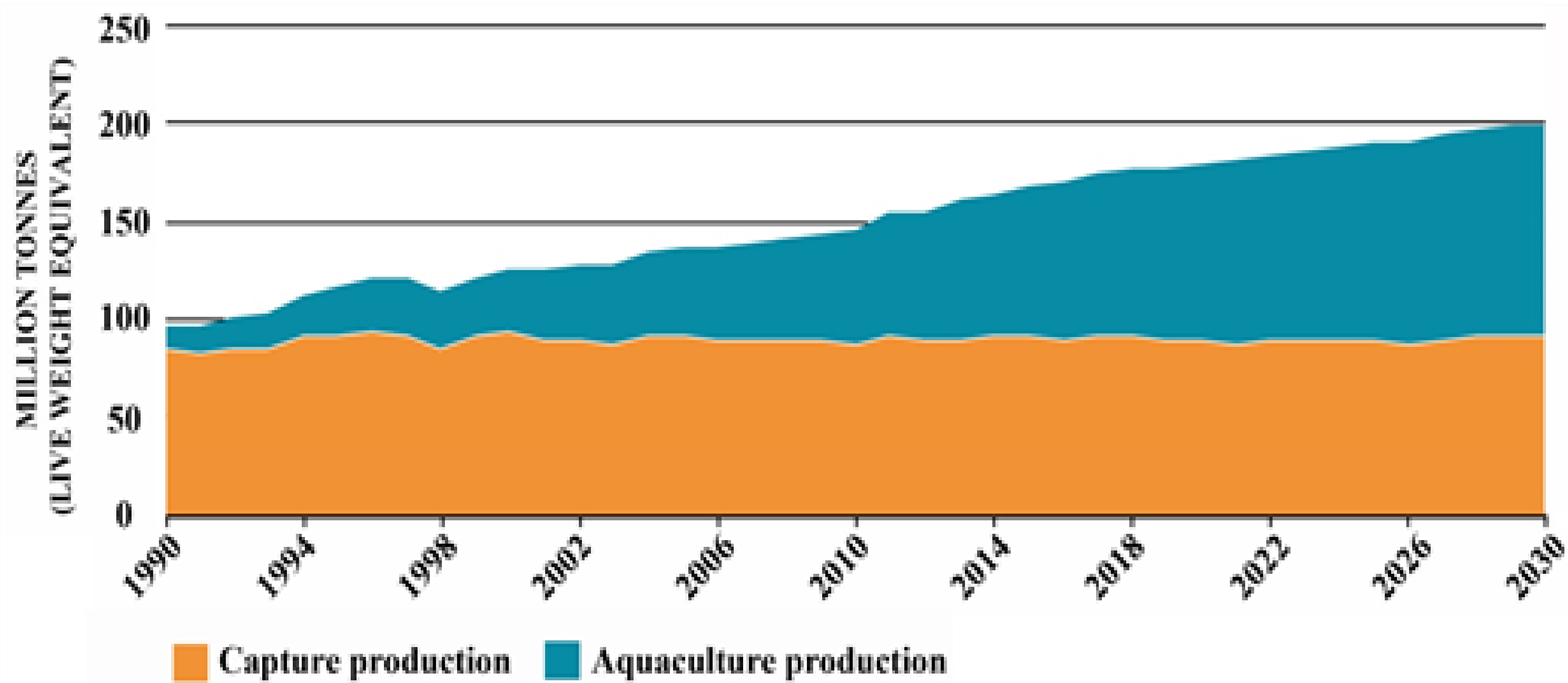
AQUACULTURE INTENSIFICATION AND EMBODIED RESOURCE UTILIZATION

D. E. Brune
Professor of Bioprocess and Bioenergy Engineering
University of Missouri, Columbia, Mo.

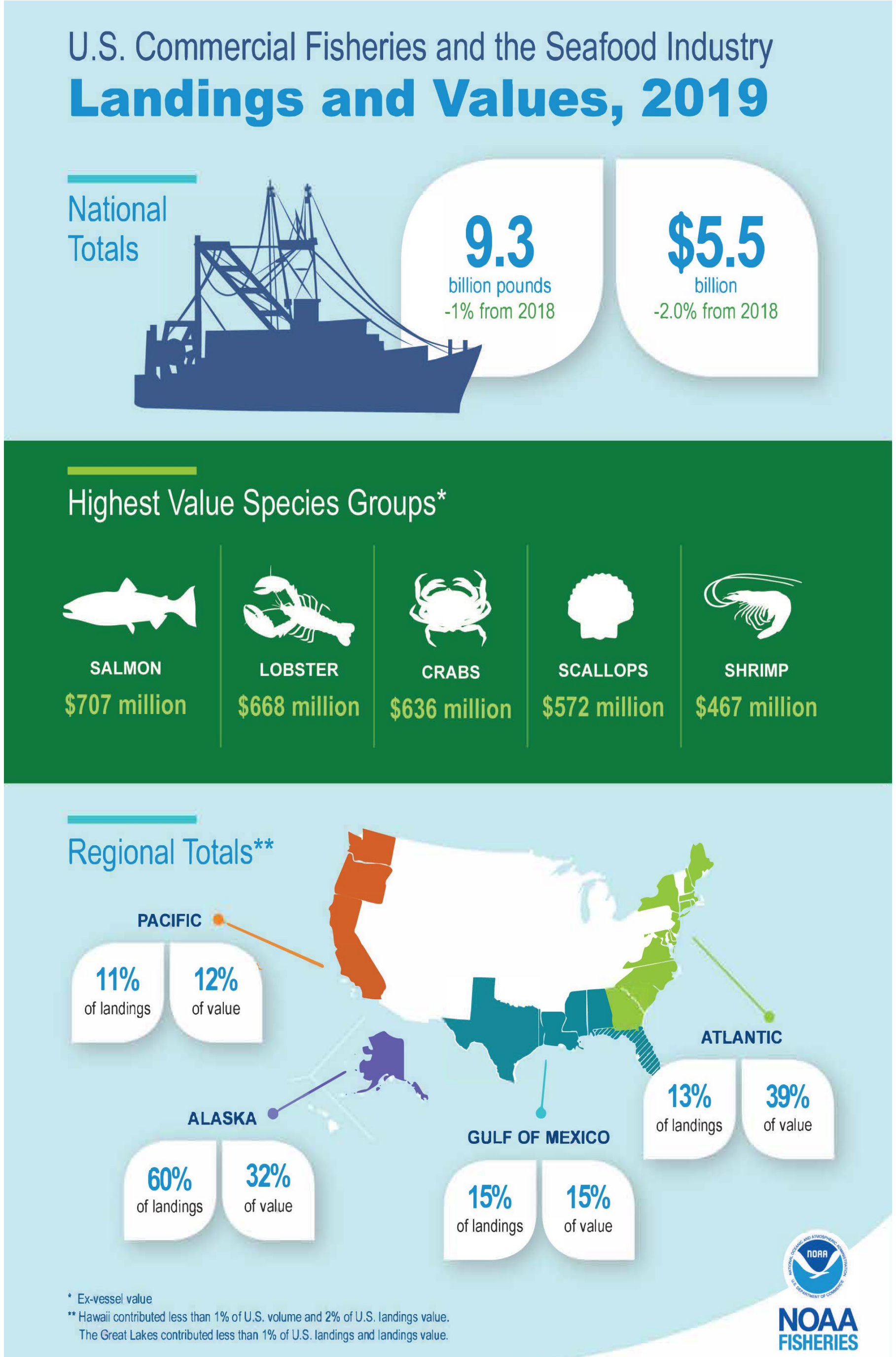
Aquaculture of Growing Importance

Global Marine and Freshwater Seafood Production

Global Aquaculture Currently Supplies 50%



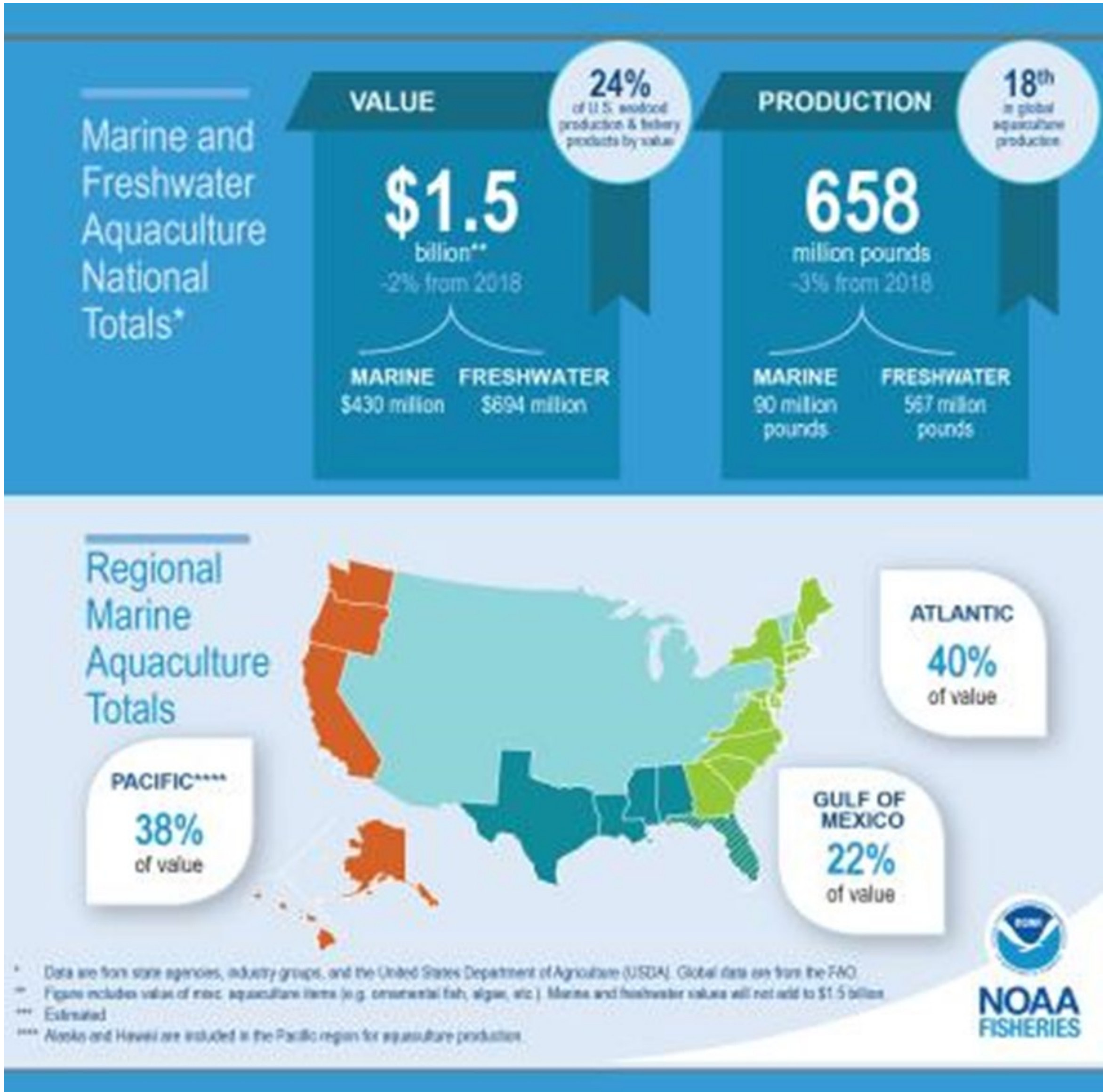
Within the last 30 years, aquaculture production of marine and freshwater fish/shellfish has grown from 5% to 50% of global seafood supply and is expected to continue to expand.



Global Seafood Production; 392 billion lb/yr in 2020, of which 192 billion lb/yr was provided by aquaculture (FAO, 2022).

U.S. Seafood Catch; 9.3 billion lb/yr, with an additional 6.8 billion lb/yr (2021) of seafood product imported.

U.S. Aquaculture Production; Estimated at 658 million lb/yr (7.1% of catch), with U.S. trout at 36 million lbs/yr and U.S. catfish at 307 million lbs/yr (NOAA 2020). Small, but of growing importance

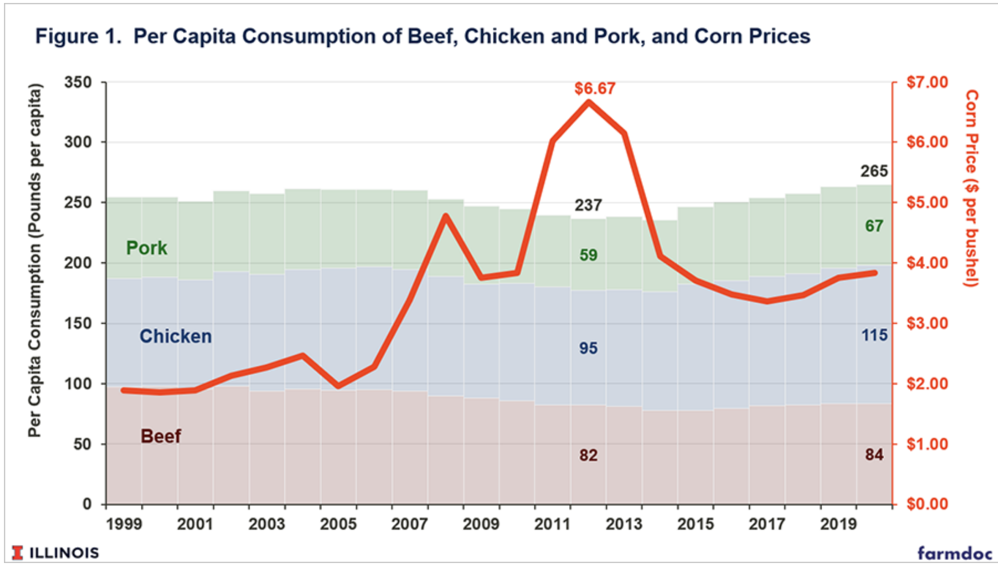


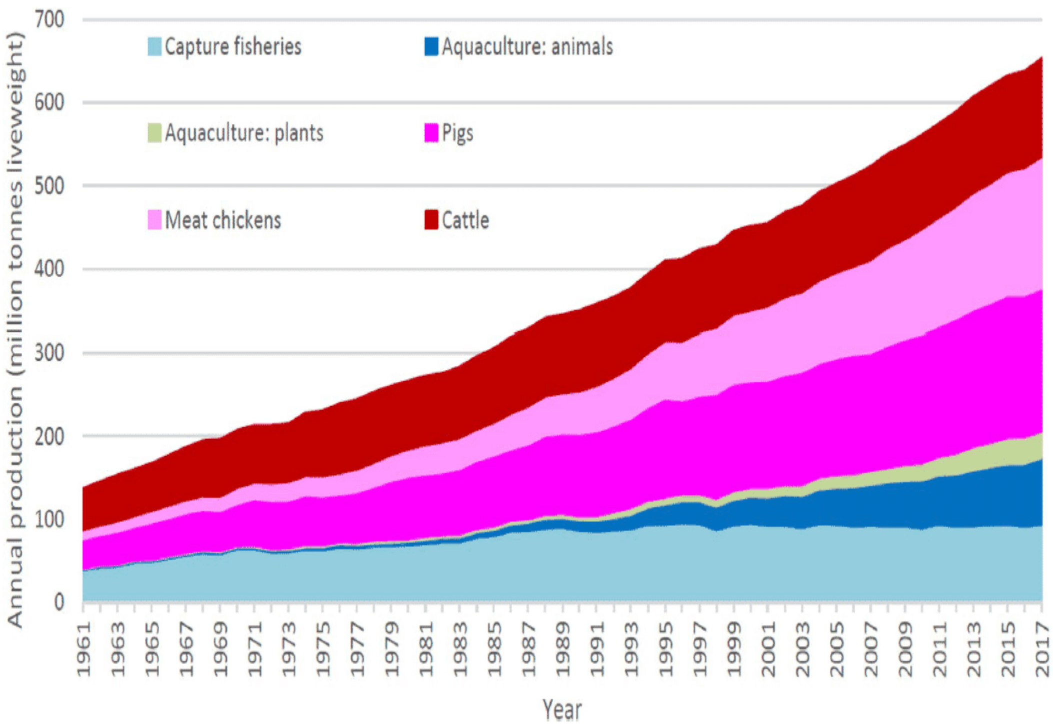
Quantifying Impact of Aquaculture Resource Usage

Life-cycle analysis (LCA) or embodied resource use (ERU) is frequently used to assess the impact of agricultural practice on the environment. The use of land, water, and energy per unit production, and emissions of greenhouse gases (GHG) provides measure of relative environmental impact of selected practices (U.S. EPA 2006) **ERU** more directly related to production process, LCA broader with less control by local operator

U.S. Per Capital Seafood Consumption 50-66 lbs live-wt/person-yr or 15-16 lbs product/person-yr (6% of livestock consumption) (MacLeod et al)

U.S. Beef, Chicken, Pork Average Consumption 84 lb-beef/yr, 115 lb-chicken/yr, 67 lb-pork/yr (266 lb/person-yr combined) (Kuck et al).





Assumptions, Conversion Factors, Energy/GHG Ratios, Water/kg

Critical ERU parameters for aquaculture; Feeds, Water, Energy, GHG emission rate

GHG emission as (kg-CO2)/3.66 = kg-C
(kg-C/kg live weight) x (2.5–1.7) = kg-C/final product weight

Feeds typically constitute 75-95% of energy consumption. Boyd suggested 314 liter embodied water/kg-feed for catfish feed production. Predicted embodied energy usage is 1.4 kw-hr/kg-feed (Biniam)

The U.S. EIA GHG emission rate; Electricity generation/transmission, GHG emission rate of 0.106 kg-C/kw-hr, diesel 0.069 kg-C/kw-hr, gasoline 0.066 kg-C/kw-hr, natural gas 0.0494 kg-C/kw-hr, propane at 0.0587 kg-C/kw-hr.

Oxygen aeration used in aquaculture; 1.1 kw-hr/kg-oxygen; At a transfer efficiency ranging 60-90%; Net energy = 1.22 to 1.83 kw-hr/kg oxygen supplied.

Energy Usage in Low-Yield Pond Aquaculture

Asian catfish, carp and tilapia ponds (Robb).

	Bangladesh	India		Vietnam
	Nile tilapia	Carp 1	Carp 2	Striped catfish
Stocking size (g)a	15 (1 – 50)	160 (50 – 300)	210 (50 – 600)	27 (20 – 30)
Harvest size (g)a	310 (180 – 750)	1240 (1000 – 2000)	2340 (1350 – 3000)	880 (750 – 1020)
Total harvest/year (tonnes/year)	52	135		1480
Total harvest per square metre of water (kg/m2/crop)	1.930	0.995		34.9
Grow out time (days)	184	230		220
eFCR (economic feed conversion ratio)	1.59	1.8		1.69
Survival (%)b	88	98c		80

Direct energy = 0.1 kw-hr/kg with indirect energy use estimated at 1.5-3.0 kw-hr/kg. Water usage less than 454 liter/kg live weight. GHG emissions were calculated at 0.37–0.50 kg-C/kg-live fish, with 57-80% of GHG coming from feed production at average FCR ranging from 1.6-1.8/1.

Energy Usage in Recirculating Aquaculture; Ranges widely from 3-80 kw-hr/kg (of live wt.). Highest range for hatcheries or small fish production. For food-fish typical RAS aquaculture energy requirements range between 7-12 kw-hr/kg live-wt (Badiola et al).

Literature values for species, country, production volume, harvest weight, energy source, and energy consumption per live-weight

Species	Country	Production (Tn)	Harvest weight (kg)	Energy source	Energy (kWh/kg fish)
Turbot	France	70	1.2	Fossil fuel	81.5
Artic char	Nova Scotia	46	1.5	Fossil fuel	22.6
Turbot	Spain	3500	1.0	Fossil fuel	20.0
Salmon smolts	Pacific Northwest	192		Fossil fuel	80.6
Trout (FCR 0.8)	France	478		Nuclear	16.1
Trout (FCR 1.1)	France	478		Nuclear	17.7
Rainbow trout	Denmark	1		Fossil fuel	19.6
Trout	Iran	1000		Fossil fuel	8.1
Salmon	USA	3300		Hydropower	5.4
Pompano	Florida	0.43	0.6		40.3
Atlantic cod	Spain	1.0		Fossil fuel	29.4
Sea bass	Tunisia	2500	0.4	Fossil fuel	49.2
Salmon smolts	USA	11,246			19.0–26.0
Rainbow trout	USA	2.5			2.90

RAS system producing trout at lowest direct energy of 2.9 kw-hr/kg. Projected oxygen demand is 3.28 kg-O2/kg fish. The embodied energy requirement associated with feed estimated at 2.1 kw-hr/kg x 1.5 kg feed/kg fish 3.15 kw-hr/kg fish = net energy requirement of 9.3 kw-hr/kg-live weigh. This suggests an estimated net GHG emission of 1.0 kg-C/kg-live weight.

Water Usage in Conventional Catfish Aquaculture (6,000 kg/ha yield) is 1,132-3,000 liters/kg plus additional 500-682 liters/kg of “embodied water” associated with fish feed (at FCR 2.0/1) (Boyd).

Resource*	Direct Use	Embodied Use	Total Use
Land (ha/tonne)	0.208	0.595	0.803
Water (liter/kg)	3,000	682	3,682
Energy (kw-hr/kg)	1.67	2.8	4.5

*Direct use of resources compared to embodied resources (feed) to produce catfish, 2.0 FCR at 6,000 kg/ha production .

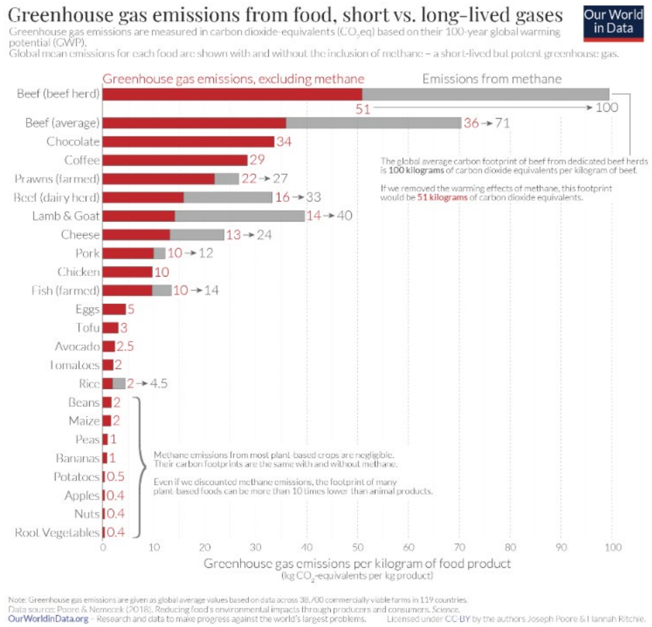
Intensive Pond Aeration or Split-Pond Aquaculture; Increased catfish yields at 12,000-18000 kg/ha, decreased water usage to 1,882-2,182 liters/kg

Direct + Embodied Water Footprint of Beef, Pork, and Poultry; 15,405, 5,988 and 4,325 liters/kg final product respectively (Mekonnen and Hoekstra), or 7,702, 2,994, 2,162 liter/kg live weight.

Livestock Energy Requirements; 69, 28 and 10 kw-hr/kg final product,(Pimentel) for beef, pork and chicken, or 34.5, 14.0 and 5.0 kw-hr/kg live weight

GHG from Livestock Production; 19.4, 3.3 and 2.7 kg-C/kg-final product (Poore and Nemcock) for beef, pork and chicken or, 9.7, 1.65, and 1.35 kg-C/kg live weight.

	Litre per kilogram	Litre per kilocalorie	Litre per gram of protein	Litre per gram of fat
Sugar crops	197	0.69	0.0	0.0
Vegetables	322	1.34	26	154
Starchy roots	387	0.47	31	226
Fruits	962	2.09	180	348
Cereals	1644	0.51	21	112
Oil crops	2364	0.81	16	11
Pulses	4055	1.19	19	180
Nuts	9063	3.63	139	47
Milk	1020	1.82	31	33
Eggs	3265	2.29	29	33
Chicken meat	4325	3.00	34	43
Butter	5553	0.72	0.0	6.4
Pig meat	5988	2.15	57	23
Sheep/goat meat	8763	4.25	63	54
Bovine meat	15415	10.19	112	153



ERU for Prototype, Zero-Discharge Controlled Climate RAS in Central Missouri

42,000 lbs/yr of striped bass within 6,000 ft^2 climate-controlled insulted metal building

Energy Consumption; 3.28 kw-h/kg for aeration, 6.3 kw-hr/kg for climate control, 2.1 kw-hr/kg for pumping, and 2.1 kw-hr as embodied feed energy; Totaling of 13.7 kw-h/kg live wt or 27.6 kw-hr/kg processed weight (Brune).

Water Usage; 504 l/kg (live wt), with 93% of water from embodied feed usage.

GHG Production; 1.4 kg-C/kg live or 2.8 kg-C/kg processed product.

Comparison of Water, Energy, and GHG Footprint Aquaculture vs Livestock Production

	Water	Energy	GHG	
	liters/kg live	kw-hr/kg live	kg-C/kg live	Source
Prototype RAS	504	13.7	1.45	25
Catfish	1,150- 3,628	4.5	0.5	12, 13
Tilapia	2,460		1.5	7, 12
Salmon	760-1,385	2.9	0.6-1.4	7, 23
Bass	1515-2921	12.7	1.3	23
Trout		11.4	1.2	24
Asian Pond	454	0.10	0.4	21
Beef	7,703	34.5	9.7	15
Pork	2,994	14.0	1.65	15
Chicken	2,160	5.0	1.35	15

The direct and embodied water, energy and GHG emission footprint for prototype aquaculture system compared to alternative aquaculture and livestock production/kg live weight. GHG gas production for beef is 6.7 times higher, and requires 15-fold more water per kg of live weight as opposed to aquaculture production

Shift U.S. Diet from Beef to Fish

U.S. beef consumption accounts for 1.9% of total U.S. GHG emissions (Broocks et al). Assuming 100% of U.S. population replaced beef consumption with seafood (produced in the prototype RAS at a GHG ratio of 6.9/1) the overall reduction in U.S. GHG emissions would amount to 1.6 % of total U.S. GHG production,

Global Soil Carbon Sequestration Potential

FAO (2022) prepared three soil sequestration scenarios, assuming an increase in soil organic matter content of 5%, 10% or 20% over a 20 yr period. Assuming worldwide change in agricultural practice, the predicted reduction in global GHG emissions as a result of increasing soil organic matter of 5% was estimated at 0.14, GTC/yr, or 1.4%

SUMMARY

Aquaculture products are predicted to require 1.5-13.7 kw-hr/kg, require 504-3,628 liters water/kg and emit 0.4-1.45 kg-C/kg live weigh in systems ranging from extensive ponds to RAS.

Beef, pork and chicken production requires 7,703, 2,994, 2,160 liters of water/kg, 34.5, 14.0 and 5.0 kw-hr/kg energy and emits 9.7, 1.65, and 1.35 kg-C/kg of live weight.

Prototype RAS GHG emission is 14.4%, water usage is 6.5% and energy usage is 40% of beef/kg.

Prototype RAS GHG emission is 85%, water usage is 17% and energy consumption 98% of pork/kg

Prototype RAS GHG emission is 104%, water usage is 23% and energy usage is 274% of chicken/kg

If 100% of U.S. population were to shift from consumption of beef to seafood, the reduction in net U.S. GHG emission is predicted at 1.6%. This is similar to 1.4% net global GHG reduction predicted by FAO if 100% of global farmland was managed to increase soil organic matter by 5% over 20 years.

.

REFERENCES

1) The State of the World Fisheries and Aquaculture FAO report, 2022 file:///C:/Users/user/Downloads/The%20State%20of%20World%20Fisheries%20and%20Aquaculture%202022%20-%20In%20Brief.pdf

2) US Aquaculture NOAA Aquaculture 2020 https://www.fisheries.noaa.gov/national/aquaculture/us-aquaculture

3) NOAA Fish watch, US seafood facts 2019 https://www.fishwatch.gov/sustainable-seafood/by-the-numbers

4) United States Department of Agriculture, National Agricultural Statistics Service, 2022, https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Trout_Production/index.php

5) U.S. imports of edible fishery products 1940-2021M. Shahbandeh Statista. 2022 https://www.statista.com/statistics/197994/us-imports-of-edible-fishery-products-since-1940/

6) EPA/600/R-06/060, May 2006, Cincinnati, OH, 2006, Life Cycle Assessment: Principles and Practices.

7) Pelletier, N., Tyedmers P., Sonsson, U., Schotz, A., Ziegler, FD, Flysjo, A., Kruse, S., Cancino, B., and H Silverman, Not all Salmon are Created Equal: Life Cycle Assessment of Global Salmon Farming, *Sci. Technol. 2009 43,* 8730–8736

8) U.S. Energy Information Administration, www.eia.gov/tools/faqs/faq.php?id=74&t=11#:~:text=This%20equaled%20about%200.855%20pounds,efficiency%20of%20electric%20power%20plants

9) Vinci, B., S. Summerfelt, Ninth Annual Recirculating Aquaculture Systems Short Course, The Freshwater Institute, Shepherdstown WV. 1997

10) Biniam, S. R., Environmental Evaluation of Aquaculture Using Life Cycle Assessment, Masters Thesis, Institute of Animal Breeding and Husbandry, Christian Albrechts University in Kiel, Germany.

11) Fletcher, R., Putting a figure on aquaculture's greenhouse gas emissions, 2020, The Fish Site

12) Yuan, Q., Song, G., Palmer, P., Wang, Y., Semakula, H., Mekonnen, M., and S. Zhang, Water footprint of feed required by farmed fish in China based on a Monte Carlo-supported von Bertalanffy growth model Water Resources and Industry, Vol 1–2, 2013, 25-36.

13) Boyd, E. E., and Aaron McNevin, 2015, Embodied Resource Use in Feed –Based Aquaculture https://www.globalseafood.org/advocate/embodied-resource-use-in-feed-based-aquaculture/#:~:text=These%20embodied%20resources%20include%20water,use%20the%20farm%2Dlevel%20inputs.

14) Leenes, G., Mekonnen, M., Hoekstras, A, The water footprint of poultry, pork and beef: A comparative study in different countries and production systems Water Resources and Industry
Vol 1–2, Pages, 2013, 25-36

15) Our World in Data, https://ourworldindata.org/

16) Mekonnen, M.M. and Hoekstra, A.Y. (2010) Water footprint of crop and animal products: a comparison https://waterfootprint.org/en/water-footprint/product-water-footprint/water-footprint-crop-and-animal-products/

17) Broocks, A., Andreini, E., Rolf, M., Place, S., The Impact of Consuming Beef on Greenhouse Gas Emissions, Oklahoma Cooperative Extension Service, ANSI-3297.

18) MacLeod, M.J., Hasan, M.R., Robb, D.H.F., Quantifying greenhouse gas emissions from global aquaculture. *Sci Rep* **10**, 11679 (2020).

19) What is the climate impact of eating meat and dairy? Food and Climate Change, 2020 https://interactive.carbonbrief.org/what-is-the-climate-impact-of-eating-meat-and-dairy/

20) Ritchie, H., R. Rosado, and M. Roser, Meat and Dairy Production, 2019 https://ourworldindata.org/meat-production

21) Robb, D., M. MacLeod, M. Hasan, and D Soto, Greenhouse gas emissions from aquaculture; A Life Cycle Assessment of Three Asian Systems, FAO, 2017

22) Van der Heijden, P., A. N. Alla. And D Kenawy, Water use at integrated aquaculture-agriculture farms< Global Seafood Alliance, 2012. https://www.globalseafood.org/advocate/water-use-at-integrated-aquaculture-agriculture-farms/

23) Engle, C.E., Kumar G., and J. van Senten, Resource-use efficiency in US aquaculture: farm-level comparisons across fish species and production systems, Aquaculture Environment Interactions, Vol. 13: 259–275, 2021.

24) Badiola M., O. Basurko, R, Piedrahita, P. Hundley and D Mendiola, Energy Use in Recirculating Aquaculture, Aquacultural Engineering, 81, 2018.

25) Brune, D.E., Resource Utilization in Heterotrophic vs Autotrophic Marine Shrimp Production, North Central Regional Aquaculture Center Meeting, 2023.

26) FAO. 2022. *Global Soil Organic Carbon Sequestration Potential Map – GSOCseq v.1.1. Technical report.* Rome. https://doi.org/10.4060/cb9002en

27) Gephart et al. (2021). Environmental performance of blue foods, in Greenhouse Gas Emission per Kilogram of Seafood

28) GHG emissions by livestock, FAO 2022 https://www.fao.org/news/story/en/item/197623/icode/

29) Xu, C., Su, G., Zhao, K., Xu, X., Li, Z., Hu Q., Xue, Q., Xu, J., Water Biology and Security; Current status of greenhouse gas emissions from aquaculture in China Volume 1, Issue 3, August 2022,

30) Kuck, G. and G. Schnitkey. "An Overview of Meat Consumption in the United States." Farm-doc daily (11):76, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, May 12, 2021 https://farmdocdaily.illinois.edu/2021/05/an-overview-of-meat-consumption-in-the-united-states.html

31) American food production requires more energy than you think. 2022, https://www.saveonenergy.com/ resources/food-production-requires-energy/

32) Pimentel, David (2009). Energy Inputs in Food Crop Production in Developing and Developed Nations. *Energies* 2,1-24, http://www.theoildrum.com/node/6252

33) Poore, J., and T. Nemcock, Reducing Food's Environmental Impacts Through Producers and Consumers, Science, Vol 260, Number 6393, 2018.

Presentations/Additional Resources

MU Extension Aquaculture Website

https://extension.missouri.edu/programs/aquaculture-extension

E-mail

bruned@missouri.edu